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RADIO BRIDGE: "EARTH-MOON-EARTH"

by V. Ye. Demidov

"Znaniye" Press
Moscow, 1967

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Translation of "Radiomost: 'Zemlya-Luna-Zemlya'," "Znaniye" Press, Moscow, 1967

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TABLE OF CONTENTS

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INTRODUCTION

The rapid growth of population on Earth and the headlong development of industry have confronted mankind with problems which almost no one on Earth thought about fifty years ago. The order of the day in the science of our era consists in the solution of such problems as guaranteeing reliable harvests in agriculture, finding new reserves of raw materials for industry, and discovering and harnessing new sources of energy. /3*

It is possible to solve these and many other problems only on the "cosmic" scale.

Without studying space, it is impossible to organize present-day service or provide agriculture, transportation or the construction industry with reliable long-range forecasts. In the opinion of many scientists, there is a real connection between the physical processes taking place on the Sun and the crop productivity and, therefore, the well-being of the Earth's inhabitants.

Space expeditions will make it possible for scientists to compare our planet with other planets in the solar system, and, in the future, with planets in other stellar systems. This will make it possible to draw fundamental conclusions concerning its origin and evolution, to become acquainted with regularities in the change of geological epochs, principles in the formation and distribution of minerals in the interior of our planet, etc.

One of the most important problems in natural science, the problem of the origin and development of life on Earth, can also be solved only by studying the stars and planets which are extremely far from Earth.

The social, economic, and political results of this closer acquaintance with space are grand. We contemporaries and participants in this assault on the skies are not in a position to guess even a hundredth of what the study and conquest of space will give science and mankind in the next fifteen to twenty years.

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* Numbers in the margin indicate pagination in the foreign text.

Science will have made a gigantic leap after the mastery of our evening satellite, the Moon. In reality, mastery of the Moon has already begun. The successful launching of the Soviet space station "Luna-1" on 2 January 1959 marked the occasion. What makes people try to get to the Moon? /4

The Moon is an ideal astronomical platform. There is no atmosphere to render frequently powerful telescopes absolutely useless and, which, by a twist of fate, disturbs most the more powerful astronomical instruments. Having set up on the Moon a telescope with a mirror of about 1-2 m diameter (the mirrors of super-powerful terrestrial telescopes have dimensions several times as large), we would be able, in the opinion of the famous Soviet astronomer, I. S. Shklovskiy, to see the gigantic Jupiter-type planets revolving around the closest stars. The significantly lower gravity, compared with the terrestrial force, will permit building telescopes on the Moon many times larger.

The absence of an atmosphere and ionosphere will aid radio-astronomers. It will be possible to construct radiotelescopes on the Moon operating in practically the entire range of electromagnetic oscillations from super-long to gamma rays. And if it is kept in mind that present-day radioastronomy has made surprising discoveries using only the relatively narrow range of frequencies which can pass through the atmosphere and ionosphere of the Earth, it will be understandable that the prospects opening up for radio-astronomy on the Moon are unlimited.

After four billion years of existence of the solar system, the planet Earth has managed to alter its face rather fundamentally. The Moon, on which there apparently never was an atmosphere, has reached the present day almost in its original form: it has not undergone either water or wind erosion, and meteorites and sharp changes in temperature obviously have not essentially altered its appearance. It is possible that the stratification of rocks and other traces of the history of the solar system have been preserved on the Moon in perfect condition. The Moon is a geological book waiting for its readers. In this respect it is incomparably more interesting for study than Venus or Mars, even though on these planets it is possible that some forms of life exist. Geologists will be able to sink shafts and boreholes on the Moon 10-12 times deeper; the low gravity is their invisible helper. Having studied the Moon, people will learn the structure of the Earth and the Universe, and this alone will repay the costs of lunar expeditions.

Soviet researchers are the pioneers in the conquest of the Moon. In January 1959, the first space station in the world reached a distance of 7.5 thousand km from its surface, carrying on board scientific apparatus for studying the physical characteristics of /5
the Moon and surrounding space.

On the 14th of September 1959, at 0 hr 02 min 24 sec, "Luna-2" station carried the Soviet banner to the Moon.

On the 4th of October 1959, the third space station entered space, reaching a distance of 7 thousand km from the night body; it transmitted in the period from 8 to 18 October photographs of the reverse side of the Moon, which had previously not been seen by mankind.

Space station "Zond-3", launched on 18 July 1965, transmitted photographs of those regions of the reverse side of the Moon which had not been photographed by station "Luna-3".

Finally, on the 3rd of February 1966, "Luna-9" station made a soft landing in the area of the Ocean of Storms and transmitted to Earth the first television report from another celestial body in the history of mankind. In the days of the Twenty-third Party Congress, delegates and guests listened to sounds of the Internationale coming from the first artificial lunar satellite, "Luna-10" station, which became a lunar satellite on 3 April 1966 and opened the era of space broadcasting from celestial bodies.

On the 28th of August 1966, a near-lunar orbit was carried out by the "Luna-11" satellite, which continued and expanded the observations made by the "Luna-10" station.

A simple listing of the principal studies performed by Soviet space stations inspires deep admiration. Along with this, it has become clear that these studies could be carried out only under conditions of completely reliable and effective lines of communication, securing transmission to the station of control commands and reception from on board the station of scientific, televised, and other information.

American scientists have had some real successes. Space stations of the "Ranger" type have sent a large number of photographs of the visible side of the Moon from various distances of several thousand to several hundred meters. In May 1966, the American station "Surveyor" repeated the achievements of the Soviet station "Luna-9", transmitting televised images of the lunar surface. In August 1966, the American station "Lunar Orbiter" started to follow the "Luna-10" artificial satellite of the Moon and transmitted to Earth pictures of the surface of the Moon.

In all these studies, success or failure of the experiment depended in large degree on reliable communications.

There is no doubt that the role of the lines of communication will be all the greater in a manned flight to the Moon.

What are the problems in creating apparatus for space communications, what are the theoretical and technological means of solving /6 the problems confronting the developers of a radio bridge "Earth-Moon-Earth"?

This is the question the author has tried to answer.

PROVIDING AN EFFECTIVE CHANNEL OF COMMUNICATION

By an "absolutely reliable" system of communications is meant a system which is capable of guaranteeing the passage of signals (for example, from Earth to a space station in the area of the Moon, and back) without distortion of the information transmitted, let alone instrument failures during the entire operating period. However, in actual communication systems, noise and signal distortion are unavoidable, and even the most reliable device has a finite probability of operation without breakdown.

Therefore, it is more correct to talk about that system of communications in which the signal distortion is within permissible limits and does not cause errors on the receiving end, that is, a system, which is sufficiently noise-free and also has a given probability of operation without breakdown, is an effective channel of communication.

Selection of the appropriate type of modulation and detection lowers the noise level at the input of the receiver; the selection of an appropriate frequency range and many other similar measures increase the noise resistance of the lines of communication without affecting the amount of information transmitted.

The resistance of a system of communications to noise can also be increased by introducing supplemental information so that static, the distorting part of a communication, cannot distort the sense of the communication. A surplus of information is introduced by an appropriate means of coding the signal being transmitted.

Finally, methods of increasing the effectiveness of systems of communication through the apparatus used include increasing the reliability of the means of constructing highly reliable groups of apparatus, duplicating groups with low reliability, and also by alleviating the electrical and thermal regimes of the apparatus.

Selection of Optimal Frequencies

From the entire varied spectrum of electromagnetic waves, practically only the range of radio waves from 15-100 MHz to $\approx$10,000 MHz is used for communication with objects in space. The /7
limits of the range are determined by space and atmospheric noises and also by attenuation which radio signals undergo while passing through the Earth's atmosphere and ionosphere. It has been accepted that this attenuation must not surpass 0.008 dB/km with the angle of the location of the radio wave relative to the Earth's surface $\beta = 90°$.

The lower limit of the range is extremely indefinite because it basically depends on the time of year and day, the geomagnetic latitude, the solar activity, and a whole series of other factors.

Radio waves of a frequency lower than this limit are reflected by the ionosphere and cannot come out into space. The reflecting properties of the ionosphere depend on the angle of descent of the radio wave; they are minimum at an angle of $\beta = 90°$. At angles of less than 90°, the radio wave is refracted and finally, because of the reduction of the angle, is entirely reflected. This is why the lower limit of the range of space communications is that frequency at which the signal begins to be reflected, sent at an angle close to $\beta = 90°$.

The upper limit of the range is determined by the absorption of radio waves by water vapors and molecules of oxygen in the air.

At a frequency of $\approx 20{,}000$ MHz, attenuation increases sharply because of absorption by water vapors, and at a frequency of $\approx 60{,}000$ MHz because of absorption by molecules of oxygen (see Fig. 1).

Attenuation at angles β, close to 0°, sharply increases because of the longer path travelled by the radio wave in the atmosphere. However, up to angles $\beta \approx 30°$, the attenuation is almost the same as that at $\beta \approx 90°$. Working at smaller angles is not suitable.

A radio wave sent by an antenna is polarized and can be received only by an antenna with a polarization surface corresponding to the polarization surface of the transmitting antenna. If the receiving antenna is turned in relation to the transmitting antenna so that the polarization surfaces do not coincide, then the strength of the signal received will drop until it is reduced to zero. This happens when the polarization surfaces of the receiving and transmitting antennas are perpendicular. A radio wave arriving from a space station (or, on the other hand, sent to this station) passes through the ionosphere which turns the polarization surface. This phenomenon is analogous to the turning of the polarization surface of light on passing through a crystal body. This is called the Faraday effect. Turning of the polarization surface unavoidably leads to signal fading; this is all the more intolerable because it can continue for a rather long time.

There are two ways of controlling this phenomenon: by going over to the area of the upper limit of the frequency range where the turning of the polarization surface is extremely slight or by /8
using antennas with circular polarization. Unfortunately, antennas with circular polarization have half the entry resistivity of regular antennas, and therefore the entering signal of the receiver is half as strong. That is why it is more expedient to go over to the area of higher frequencies.

High frequencies are advantageous from the point of view of reducing the noises at the intake of the receiver. Space noises, for example, steadily decrease with increases in frequency. At frequencies of 1,000 MHz and above, they become so insignificant that it is feasible to use in the first cascades receivers with low-noise parametric and molecular amplifiers.

Nevertheless, in spite of the fact that the frequency range suitable for space communications goes up to 10,000 MHz, radio waves at frequencies greater than 8,000 MHz would hardly be used because at these higher frequencies thermal noises from water vapor and hydrogen molecules start to appear.

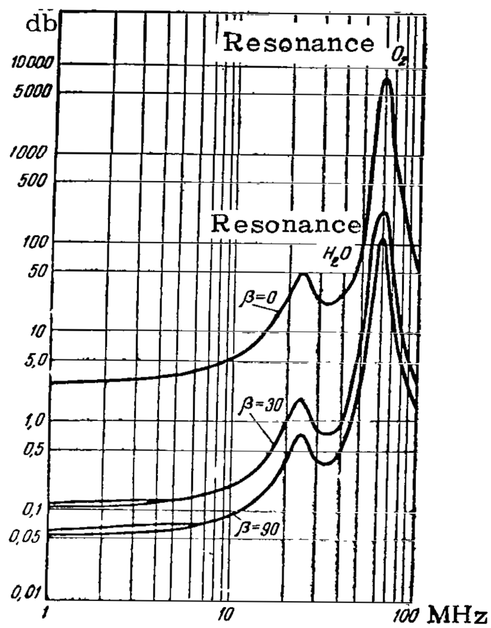


Fig. 1. Dependence of Signal Attenuation in the Atmosphere for Various Angles of Inclination of the Antenna β Relative to the Horizon.

Therefore, from the point of view of minimum noises, the most suitable range for space communications is 1,000-8,000 MHz.

Unfortunately, in our discussions we failed to consider the role of antennas. It is they which frequently are the decisive factor in the selection of optimal frequencies.

The fact of the matter is that usually space stations move in a nonstabilized manner over a large part of the trajectory. To design an omnidirectional antenna is theoretically possible at any frequency, but there are unavoidable gaps in a circular directivity diagram. With lower frequencies it is easier to construct a uniform directivity diagram. Thus, for a nonstabilized station, it is advantageous to use rather low frequencies. /9

On the other hand, the amplification of an antenna grows with an increase in the relationship of its dimensions to the length of a wave, so that, from the point of view of building sufficiently small-size and economical antennas, it is advantageous to go to the area of high frequencies.

Thus, there is no frequency which is optimal for all radio lines. To select the best frequency is possible only after having analyzed all factors; radio technical, production, and economic. An important place in the analysis is occupied by the maximum distance for which the line of communications is designed, the type of information transmitted, the technical possibilities of building transmitters of a given power and size for the chosen frequency, etc.

This approach to the problem of selecting the frequency of the line of communications explains the fact that on Soviet "Luna"-type stations, for example, a frequency close to 20 MHz was used for transmitting one type of scientific information, a frequency close to 40 MHz for another type, and a frequency close to 180 MHz for transmitting television signals and measurements of orbital elements.

Selection of the Type of Modulation

In planning a channel of communications, developers are confronted with two contradictory requirements. On the one hand, it is desirable to achieve as rapid transmission of information as possible (a system with a large volume of information), and, on the other hand, to keep the receiver noise to a minimum. The contradiction in these requirements is that increasing the speed of transmitting information is connected with broadening the transmission band of the receiver, while reducing the noise, on the contrary, requires narrowing the band.

While it is theoretically possible to create a channel of communications for operation at distances such as from the Earth to the Moon, regardless of the type of modulation used, practically speaking, with certain types of modulation, it is necessary to sharply reduce the transmission band and, consequently, so reduce the speed of transmitting information that it is extremely inconvenient to use the channel.

The effect of interference can be looked on as some sort of parasitic signal modulation. Therefore, the type of interference /10 plays a decisive role in the selection of the type of modulation. Usual atmospheric interferences and space noises are characterized, as a rule, by rapid amplitude changes. The frequency range of natural interferences is very broad, extending from super-low to infinitely high frequencies. The amplitude of interferences drops as frequency increases.

Signals in lines of communication can be transmitted principally in the form of "continuous" signals (an example of this is ordinary broadcasting and television) and in the form of coded communications in a binary code. These coded communications are basically more noise-resistant (under stable even conditions); therefore, pulsed systems are used widely in space communications. The superposition of a binary signal on the carrier transmitter, modulation, is usually called manipulation.

According to theory, of the various types of manipulation the least resistant to interference is amplitude telegraphy. More noise-resistant are frequency telegraphy and phase telegraphy. Inasmuch as phase telegraphy is more noise-resistant, its use is more preferred. However, for determining the change in the phase of the signal, i.e., the moment of transmission of zero or one, it is necessary to have a supplementary index signal providing the index phase. This situation hindered extensive use of phase telegraphy for a long time. However, in 1954 the Soviet scientist, N. T. Petrovich, proposed a new method of reception: the method of relative phase telegraphy; after this, phase telegraphy began to be introduced at a rapid rate into the technology of communications.

Professor Petrovich proposed using as the index signal, the signal of the preceding message and determining the phase of the following signal in relation to it. Determining what is being transmitted, one or zero, is accomplished in relative phase telegraphy by comparing the phases of the signal being received with the preceding message. At the beginning of communications, a control message (zero or one) is sent, which, at the same time, serves as the index message for the next one.

The resistance to interference of phase telegraphy is, as was said before, higher than the resistance of frequency telegraphy, given the same length of message and transmitter power. Another advantage of relative phase telegraphy is the possibility of reducing the transmission band of the channel of communication by one-half. This is an extremely important advantage, and on long lines of space communications (for example, on the American space line "Telebit"), relative phase telegraphy will be a system that is used more and more.

Coding

As is known it is possible to increase the noise-resistance of the line of communications, having increased the excess information in a message. Likewise, it is possible to reduce the distorted messages (naturally, distortions not exceeding the toleration limit: no excess can salvage a completely distorted message). /11

Of the huge variety of codes, the most common (chiefly because of the simplicity of the apparatus) have been uniform codes. They are called uniform because each code packet or "word" consists of the same number of binary symbols and classes (ones and zeros).

If a code word consists of n classes, it is possible, with such a code, to transmit a maximum of 2^n words. Radio lines built on this principle have minimum noise-resistance because the distortion of any class leads to an undetectable error.

What surplus must be included in a code; in other words, how many additional classes should be provided to make it possible to discover p and correct q distorted classes? Before answering this question, we must understand what is meant by "code interval" d, that is, the minimum number of classes which separate individual words in the code. For example, in a code with minimum noise-resistance, the code interval equals one (a word is separated from the next word by at least one class).

To correct q classes, the minimum code interval must equal

$$d=2q+1. \tag{1}$$

With this same code interval, the code makes it possible to detect $p = d - 1$ errors. With this, the number of words transmitted by the code,

$$N \leqslant \frac{2^n}{1+C_n^1+C_n^2+\ldots+C_n^q} \tag{2}$$

where C_n^q is the number of combinations of n symbols for q corrected classes:

$$C_n^q = \frac{n!}{q!\,(n-q)!}\ . \tag{3}$$

Assume that it is necessary to transmit only textual messages on the line of communications. There are 32 letters in the Russian alphabet, and, to transmit any of them, it is enough, in principle, to have a code of five classes $2^5 = 32$.

TABLE 1 /12

Code Interval	No. of Distorted Classes		Max. Number Words Transmitted in the Code
	Detected	Corrected	
d	p	q	N
1	0	0	2^n
2	1	0	2^{n-1}
3	2	1	$\frac{2^n}{1+n}$
4	3	1	$\frac{2^{n-1}}{n}$
$2q+1$	$d-1$	q	$\frac{2^n}{1+C_n^1+C_n^2+\ldots+C_n^q}$

Inasmuch as this code has minimum noise-resistance, it is desirable to transform it into a code in which at least one mistake will be detected. For this it is necessary to add to every word in the code one control class, as presented in Table 1. After this the code will have the form:

$$a_1a_2a_3a_4a_5a_6 \tag{4}$$

One appears in the sixth class when an odd number of units is in the first five classes; in the opposite situation, zero will appear in the sixth class.

Errors are detected in the following manner. The arithmetic structure of the receiver of such a code must be such that

$$a_1+a_2+a_3+a_4+a_5+a_6=0. \quad (5)$$

on adding them in values of 2, that is controlled by the rules of adding binary numbers (0 + 0 = 0; 0 + 1 = 1; 1 + 0 = 1; 1 + 1 = 0).

If the rule of evenness is not complied with (i.e., one of the classes is altered), the sum will not equal zero. Such words are considered unreliable and are excluded.

It should be noted that this code does not prevent alterations of two classes, nor will a check catch an error if there is an altered one in one of them and an altered zero in the other.

To detect two errors (and correct one of them), three classes must be added to the five-class code. With an increase in the number of errors caught and corrected, the surplus in the code grows /13
quickly; to correct three errors, it is necessary to have a fourteen-class code.

The principles for constructing apparatus for correcting errors are rather complicated and are not treated in this brochure.

Methods of Using Apparatus to Increase the Reliability of Channels of Communication

Any methods for improving the noise-resistance of channels of communication will come to naught if the apparatus on board the station are not highly reliable and are not in such condition as to perform assigned functions.

It is known that the probability of the "safe existence" of a man for a year (e.g., the probability that he will not perish as the result of an automobile or airplane accident, will not be poisoned, will not fall off a cliff, etc.) equals 0.997. For us living on Earth, such a probability is completely satisfactory, and we would, apparently, be content if we could achieve such a degree of probability for space apparatus. In practice this means that for a lunar expedition lasting, let's say, 150 hours (one and one-half days to the Moon, the same back, and two days on the Moon) an apparatus must be created in which the frequency of failures must not exceed one in 30,000 hours ($\approx$3.5 year) of continuous operation. Anyone who has had a broken television set will agree that this is an extremely high degree of reliability.

The complexity of designing such a highly reliable apparatus is heightened by the extremely arduous conditions under which it works in spacecraft; large temperature drops, strong vibrations, etc.

Increasing the reliability of apparatus at the present time is done by the two methods: by redundancy and by reducing the load of the electrical and thermal systems.

Any cascade, block, or system can be reconstituted in the form of some number of less complex structures, connected sequentially, in parallel, or mixed. The hierarchy of such a rearrangement begins at the junction in the system of the separate blocks and instruments, then, in turn, at the junction of individual units, and at the units which are the junction of individual radio elements.

An element out of order leads, at the minimum, to a deterioration of the output parameters of the block and, in the long run, of the system.

Therefore, designers pay great attention to the correct matching of elements and their systems, and also to the possibility of using redundant elements and, if necessary, employing redundant instruments and even systems. /14

Failures of elements are divided into two types, the unexpected failure and the slow deterioration of the parameters leading finally to an intolerable alteration in the operation of the cascade. Unexpected failures usually result as a consequence of a hidden flaw, overlooked in the manufacture of the element. As a rule, these failures appear in the first hours of operation, in the so-called "running-in period". After the end of this "running-in period", a period begins during which the probability of failure drops sharply and remains at this level for a rather long time. After this, as the elements wear out, the probability of failure rises again.

The time after the "running-in period" and before the elements wear out is the most advantageous for using the apparatus. It is just this period that is meant when speaking about the probability of failure, performance in hours for one failure, etc. Redundant elements of the apparatus are effective also only in case of operation in this period.

If the layout consists of n devices, connected sequentially, then the probability of faultless operation $P_0(t)$ for such a layout is equal to the product of the probabilities of faultless operation of each element

$$P_0(t) = P_1(t) \cdot P_2(t) \cdot \ldots \cdot P_n(t). \quad (6)$$

With an increased number of cascades or blocks, the probability of faultless operation drops rapidly.

If reliability is increased by general reservation, that is, by switching in parallel the reserved device (composed of N sequential elements) m of the same devices, then the probability of faultless operation $P_{gen}(t)$ grows in accordance with the formula

$$P_{gen}(t)=1-[1-P^N(t)]^{m+1}\ , \tag{7}$$

where $P(t)$ is the probability of faultless operation of one of the N element. In practice, discrete reservation, that is, reservation of each N element m times, is frequently resorted to. With this the probability of faultless operation $P_{disc}(t)$ rises to

$$P_{disc}(t)=\{1-[1-P(t)]^{m+1}\}^N\ . \tag{8}$$

General reservation has a comparatively small effect. The discreteness very basically improves the reliability of the apparatus. /15

For example, a system of ten elements with a probability of each element of $P_i(t) = 0.8$ guarantees, under a two-fold general reservation, an overall reliability of the entire system of $P_{gen}(t) = 0.27$, and with discreteness, $P_{disc}(t) = 0.92$. Without reservation such a layout would have had an overall reliability of $P_0(t) = 0.11$.

An example of reservation of electronic units used in the American satellite OAO is given in Figure 2.

Of course, it is impractical to reserve to the same degree all units and blocks. The optimal system would be one in which all

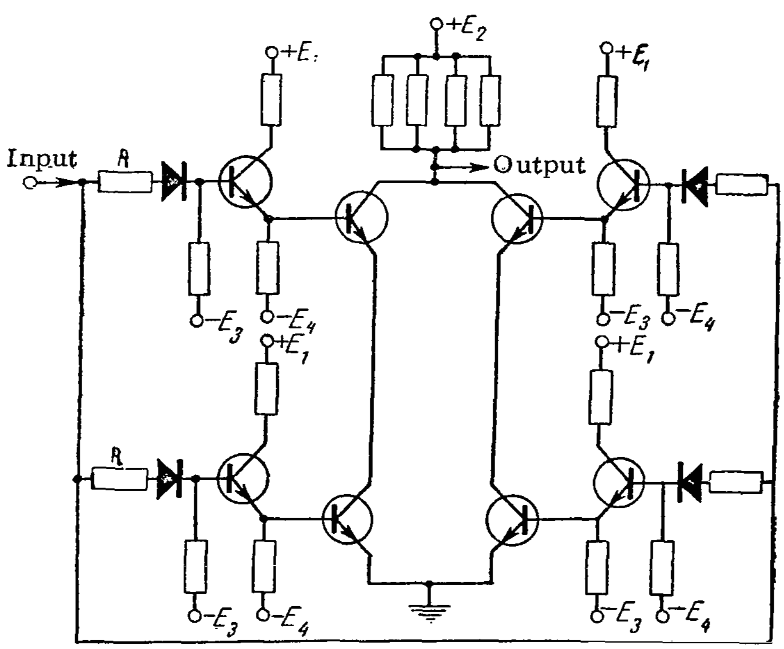


Fig. 2. Redundancy Layout of Invertor.

apparatus and blocks are equally stable. Therefore, by one or another method of reservation and reducing the load of the operating system, an effort is made in planning to approximate the probability of reliable operation of each unit to some previously determined level, guaranteeing the required reliability of the system as a whole.

There is no economy in building, for example, a commutator for a telemetric system with a reliability of $P_1(t) = 0.99$ if the transmitter on which the signal from this commutator comes has a reliability of $P_2(t) = 0.2$. /16

On the contrary, if the output block of the system has a high degree of reliability, there is sense in "adjusting" its reliability with the preceding blocks (assuming that is possible).

Reducing the load of the operating systems of radio elements consists of reducing the scattering of power, operating voltage and current, etc. Reducing the scattered power improves the heat system of the parts and significantly increases the operating reliability of the apparatus.

Thus, for type TVO* resistances, lowering the scattering of power by half (i.e., going to a coefficient of load of $K_l = 0.5$) reduces the probability of failure five times, while lowering the temperature of the surrounding environment by half only reduces the probability of failure three times (calculating on the basis of a thousand hours of operation).

The relationship between reducing the number of failures and reducing the load of the operating system is even more marked in the case of condensors. Selecting a load coefficient to voltage of $K_l = 0.5$ reduces the probability of failure ten times!

However, even during operation with a reduced load system, a change in the nominal parameters of radio elements occurs (capacity, resistance, the amplification coefficient, and others change). Consequently, the cascades gradually deviate from their calculated regimes, leading to a failure of the block in which they are installed. In this failure, the element does not break down, and calculation of such a failure is difficult. Therefore, in planning, the nominal values of radio elements are selected so that, when they deviate from the nominal, the network will continue to function normally.

Naturally, to sort through all the possible combinations of values of elements in a reasonably complicated cascade is almost impossible, but such a sorting is extremely necessary to determine the optimal field of operation of the cascade. Therefore, for this purpose, so-called matrix test automatic devices have been designed which, following an input program, change the nominals of elements of cascades within given limits, check the working capacity of the circuit in each of the combinations of elements, and record the

* Translator's comment. This is not a standard abbreviation and the meaning is not clear from the text. It possibly means high-ohmic current.

number and nature of failures. This allows designers to select the fields of nominals in which the operation of the cascade is most stable.

The most important method of increasing the reliability of an apparatus is the method of boundary tests. In this method the voltage fed to the block or system changes. This leads to a change, usually for the worse, in the output parameters. The less competently the apparatus is planned, the more the parameters change. This type of test is especially effective for large systems and those cascades which, because of their complexity, have circuits which cannot be checked by the matrix method. /17

All of the measures, both in theory and in practice, make it possible to design an apparatus which works under space conditions for an extremely long period of time. For example, the connection with the Soviet interplanetary station "Mars-1" was maintained for almost five months at a maximum distance exceeding 100 million km.

PROBLEMS SOLVED BY COMMUNICATIONS SYSTEMS ON THE LINE "EARTH-MOON-EARTH"

The radio link "Earth-Moon-Earth" can solve, in principle, such problems as communication with space stations as well as communication between isolated points on Earth, using the Moon as the relay point.

In the first case, the line of communications usually transmits a control command from Earth to the station and from the station to Earth: signals of extratrajectory, telemetric, scientific, and televised information.

In the second case, the type of information is wholly determined by communications stations on Earth [naturally, within limits, fixed by possibilities of an active (future) relay point located on the Moon or by passive relay properties of the Moon].

An apparatus working under the conditions of space is distinctive for characteristic features which affect the principal decisions in organizing lines of communication. These features include the low power of onboard sources of power and associated limited output power of the transmitters, the insignificant effective area of onboard antennas and their small coefficient of amplification, the comparatively low sensitivity of onboard receivers, and so forth.

The limited power potentials of onboard apparatus in creating effective space radio lines makes it necessary to transfer the basic burden for securing communications to the apparatus on Earth.

On Earth powerful transmitters are created, gigantic antennas with extremely large coefficients of amplification are erected, the signal received is amplified by highly sensitive receivers in /18 which the most recent achievements of solid state physics are incorporated, and other means of increasing the operational quality of the radio line are used. In the future it will be possible to take the receiving antennas and receivers to the artificial Earth satellites.

The trajectory of a station during flight is continuously controlled by apparatus in the complex of extratrajectory measurements on Earth. Data from the measuring points from radar stations of various types reach the coordinating computer center where electronic machines determine the flight trajectory of the station from the data received, compute the necessary corrections, and issue commands for the correction of travel. These commands are transmitted to the space station on the command radio line (CRL).

The functioning of the onboard apparatus and the passing of commands transmitted on the CRL are controlled by the radiotelemetry system (RTS). It also transmits to Earth the results of scientific observations, keeps track of the temperature inside and on the surface of the station, the pressure in the instrument compartment, and so forth. The RTS is one of the most important onboard systems, permitting scientists and developers to evaluate the operational quality of the station and to analyze the causes of failures.

Lastly, some space stations are equipped with television or photographic television stations. Space television is marked by a high quality image. Unfortunately, at the present time it is capable of transmitting only stills at great distances. The low power of the transmitters limits the penetration band of the lines of communication and the speed of transmission of information.

During the flight of the station near the Moon or revolving around the Moon in the orbit of a satellite, the image on the screen of the transmitting tube will change rapidly, but the low speed of transmission will not permit transmission of this rapidly changing image to Earth. Preliminary exposure of the image on film makes it possible to keep the image for an almost unlimited time so as to transmit it later at a slow rate as a still. This is how "Luna-3" and "Zond-3" transmitted images of the Moon. "Luna-9", resting on lunar soil, put an image of the Moon's panorama directly into ether.

All of the systems enumerated are the heart of advanced contemporary technical thinking. Therefore, there is logic in examining each of them individually.

Control System /19

The onboard control system of a space station, like any other control system, consists of a receiver, a command decoder, and actuating mechanisms which operate in compliance with commands received.

The feature of the onboard receiver is its exceptionally small power requirement, inasmuch as the receiver usually works during the entire flight in an "on-duty" condition, waiting for commands from Earth. There exist, at least in principle, those systems in which the command receiver normally is shut off and periodically is turned on at previously calculated moments on command of the on-board command programming unit (OCPU).

Commands to a space station are usually received in a coded (binary code) form. The command can be formulated on Earth by various methods, particularly by a formulater on the delay line.

The pulses from the command pulse generator pass through the delay line with discharges, occurring sequentially at each discharge with a definite delay for the given discharge. As a consequence of this, on the summing diagram the sequence of pulses is separated into units of separate intervals, the length of which we can represent by a number of zeros.

This is the sequential means of transmitting the code of a command.

In parallel transmission of a code, each series, for example, has its own subcarrier frequency, and the presence of it in the signal spectrum indicates one and the absence indicates zero. In this method of transmitting each command, a definite combination of these subcarrier frequencies corresponds to each transmitted number.

On the Soviet stations "Luna-3", "Luna-9", and "Luna-10", orientation systems were switched on by CRL, sending commands for preparation for photographing and for transmission of a television signal. However, in the concluding section of the flight of "Luna-9" and "Luna-10" stations, control by radio was not sufficiently operative, and therefore by command from Earth these stations went over to an autonomous system of control. Data required for correcting operation of autonomous systems of control were also transmitted to the station from Earth on CRL.

Because the requirements for accuracy in the response of "Luna-9" and "Luna-10" were basically higher than in the launching of the other "Luna" stations, a trajectory correction was carried out during flight. The data required for the correction, transmitted by CRL to the stations, sent the command for switching on the autonomous control system, and all subsequent operations: orientation, switching the engines on and off, etc., were carried out with the autonomous system. /20

The American "Ranger" and "Surveyor" lunar stations were controlled by command radio lines.

System of Extratrajectory Measurements

Calculations for the commands for trajectory correction were made, as has already been said, from data of a number of extra-trajectory measurements. For these measurements data are produced on the angular coordinates of stations in the computed system of coordinates (for example, at a right angle from center to the center of the Earth), on the distance and the speed relative to the Earth. All these values are measured with great accuracy by radio methods.

The angular coordinates can be measured by various methods, and, in particular, by phase-meter methods.

In a very simplified way, this method includes the following. The transmitter signal from the space station is received on Earth on two antennas: A_1 and A_2 (Fig. 3), separated from each other by a distance of l. Since the distance to the transmitter is incomparably greater than the distance between the antennas, we can consider that the incident wave is on a plane, and that both lines of "antenna-transmitter" sighting are parallel to each other.

The delay of a signal approaching antenna A_1, in comparison with antenna A_2, is equal to

$$\tau = \frac{h}{C}, \tag{9}$$

where $C \simeq 300{,}000$ km/sec is the velocity of radio wave emission in a vacuum.

On the other hand, the distance h is equal to $l \sin \alpha$, i.e.,

$$\tau = \frac{l \sin\alpha}{C}. \tag{10}$$

It is well known that the phase angle of a signal $\Delta\phi$ is expressed by the delay time τ and the vibration period T as

$$\Delta\varphi = 2\pi \cdot \frac{1}{T}\tau. \tag{11}$$

Expressing τ in terms of (11), we obtain

$$\tau = \frac{\Delta\varphi \cdot T}{2\pi}. \tag{12}$$

Then angle α, which gives the direction to the transmitter, and which is expressed in terms of (10) and (12), will be determined in this way: /21

$$\alpha = \arcsin \frac{\Delta\varphi \cdot C \cdot T}{2\pi \cdot l} = \arcsin \frac{\Delta\varphi \cdot \lambda}{2\pi \cdot l}. \tag{13}$$

Thus, accuracy in measuring the direction to the space station depends on accuracy in measuring the phase angle of the signal between the antennas, accuracy in measuring the base, and accuracy in maintaining the frequency of the onboard transmitter.

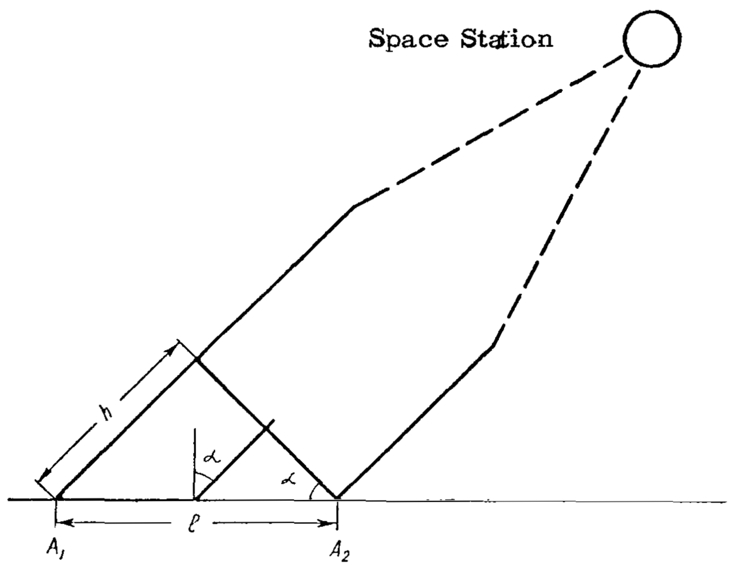


Fig. 3. Scheme of Formation of Phase-Difference Signals in a Phase-Meter Radar System.

We can easily note that various angles α correspond to one and the same value for the phase angle $\Delta\phi$, namely: the angles which differ from each other by a value of $\frac{\lambda}{l}$, since in this case the phase angle changes roughly by 2π. As a result of this system with a base greater than λ, we cannot give, in principle, an unequivocal value for the α angle. On the other hand, it is possible that a greater increase in the length of the base is necessary for increasing the accuracy of the calculation.

We can succeed in reconciling these contradictions by introducing a method for discovering the ambiguity in the phase-meter system. Various methods are used for this purpose. For example, we can introduce one more antenna, A_3, which is separated from the A_2 antenna by a distance of $\frac{l}{2} + 0.5\lambda$.

Then the sum of the different-phase signals from the A_1 and A_3 antennas and the A_1 and A_2 antennas is equivalent to the signal received from antennas located at the base λ. Thus we succeed in showing the direction, although very roughly, and in solving the problem of discovering the ambiguity. The resolving power on a rough scale in this case must be not worse than $\frac{\lambda}{l}$. /22

If we do not succeed in obtaining such a resolving power on a rough scale, we will introduce one or more intermediate scales, each of which solves the problem of discovering the ambiguity for a scale of a smaller range.

Accuracy in phase-meter systems is very high. One of the foreign stations ("Azuza") can guarantee a calculated error of not more than $1 \cdot 10^{-6}$ at distances up to 400 million km. The error arises mainly because of an inaccurate value for the velocity of light in a vacuum.

Telemetric Measurements

A block-diagram of one of the variations of a telemetric system is given in Figure 4.

The sensitive elements of the system are the data units which convert non-electrical values (pressure, temperature, velocity, acceleration, etc.) into electric signals.

The data unit very frequently takes the form of a potentiometer, the deflection angle of the arm of which, and subsequently its output voltage, are proportional to the measured non-electric value. The dependence between the voltage and the value of the non-electric parameter is determined previously with the aid of calibrated tables and graphs.

The contact pickups which are widely used are the locking and releasing contacts which signal a fault in the heat-resistant cone of the station, separation in the last stage of a booster rocket, etc.

Together with these pickups, which are simply constructed, there exist, and are frequently used, extremely structurally complicated and expensive pickups. Such, for example, are the gyroscopic pickups of accelerations and the inertial accelerometers. Their role in the control of trajectories and in the regulation of the space station and rocket is exceptionally great.

The number of pickups on objects in space is comparatively small, or, in any case, much less than on a booster rocket. Thus, for example, the telemetric system of "Pioneer-V" station transmitted information only from 24 pickups, while the telemetric system of one of the foreign rockets transmits information from more than 200 pickups.

In connection with the fact that, for transmission of information from all the onboard pickups, there is, as a rule, only one radio channel, measures are taken for its multiplexing. /23

The multiplexing can be partial when each pickup corresponds to its subcarrier frequency at which the information is transmitted solely from this pickup, and the information from all the pickups is transmitted simultaneously. The multiplexing can also be by time division - when all the pickups are examined in sequence, and the inquiry of each one takes only some part of the time for interrogation of all the pickups.

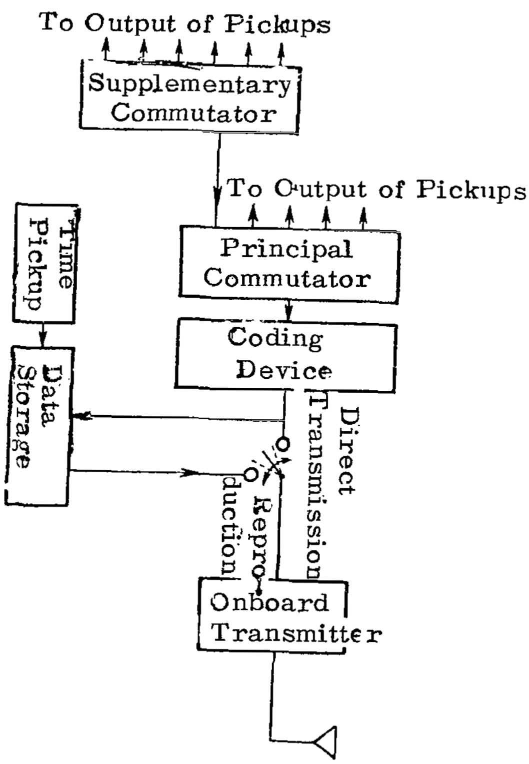


Fig. 4. Block Diagram of the Telemetric System with Graded Commutation and Data Storage.

The pickup outputs in the system with time distribution of the channels (namely, that system which is shown in Fig. 4) are examined by the principal commutator. We will speak about the supplementary commutator later.

According to Kotel'nikov's theorem, for an accurate transmission of a signal with a frequency band of Δf, it is necessary to interrogate the pickups with frequency f_{int}, whereupon

$$f_{int} = 2\Delta f. \qquad (14)$$

The type of commutator is determined, in particular, by the maximum rate of switching of the channels and by their number.

Electronic commutators provide for operating with rates of switching which are measured by hundreds and thousands of cycles per second. Mechanical commutators rarely guarantee switching rates greater than several tens of cycles per second. In this case, as the rate increases, the deterioration of the mechanical commutator sharply increases, and its operational life is shortened. The operational life of electronic commutators is hundreds and thousands of times greater than for the mechanical ones. /24

However, for low inquiry rates, the mechanical commutators operate very reliably. In this case, their volume is 2-4 times less, and their cost is 1.5-20 times lower, than for electronic commutators (calculated for one channel). Moreover, for a relatively small number of channels and a low inquiry rate, the mechanical commutator requires much less energy.

From the commutator output, the signal goes in either the coding device (if the RTS system operates in a transmission regime) or the data storage, when, for some reason or another (lack of communication with the tracking station because of the diurnal rotation of the Earth, etc.), transmission is impossible.

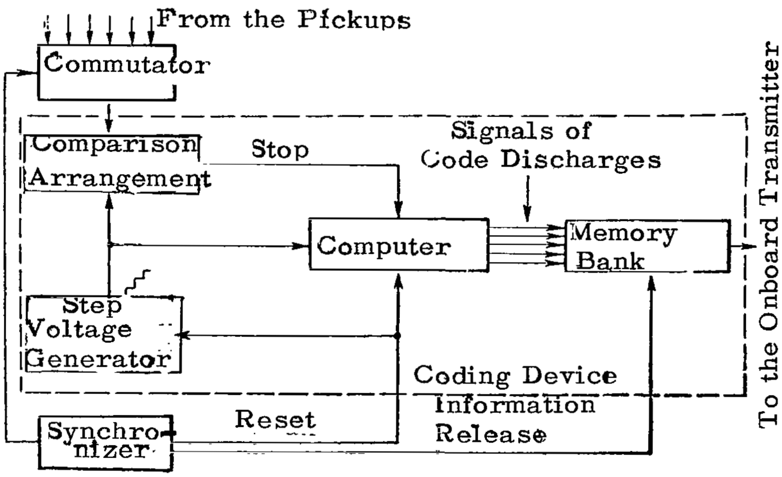


Fig. 5. Diagram of the Coding Device of a Digital Telemetric System.

The coding device converts the voltage fed into it from the commutator output into a code which is convenient for transmission (for example, a binary code). In this case the conversion can be made by comparing the input voltage of the coding device with the gradual sawtooth voltage developed inside the coding device (see Fig. 5). At the moment when the input voltage and the gradual voltage are found to be equal, a special diagram can count up the number of "used" stages. The calculation is made in a binary code. The number being formed is stored for a short time by the memory register so that it can be transmitted subsequently through the transmitter, discharge by discharge. But during the transmission, /25 the voltage of the subsequent channel is fed into the coding input, and this is compared with the sawtooth voltage. A special synchronization junction controls the operation of the coding device.

Remembering the information during no communication is usually done by recording on a magnetic tape, in the form of a binary code, again. The signal from the coding output in this case does not go into the transmitter, which is turned off in order to save power, but it does go in the data storage (DS). The code can be taped, for example, in a parallel way: by several tracks immediately, where each discharge leads off its own track. Magnetization of the tape to saturation by magnetic flow of one sign corresponds to zero, and of the other sign, to one. This method is convenient in that it is not necessary to remagnetize the tape after recording.

Very rigid requirements for the absence of any effect of individual tracks on one another, as well as on a parallelism for all operational gaps, are set forth for the magnetic tape attachments. A non-parallelism results in the amplitudes of reproduction signals for different tracks being obtained for varying values, which is very undesirable, since the reproduction amplifiers are standard for each of the tracks.

Since the information has significance only in that case when it is linked with time, the signals of the time pickup (electronic hours) are recorded simultaneously with the recording of signals from the telemetry pickups.

After having restored communications with the space station, the DS transmits to Earth information at an increased rate in comparison with the memory. The information from the data storage goes directly to the transmitter, and after everything is transmitted, the transmitter input is switched to the output of the coding device.

The question may arise: how can we decode on Earth the information from pickups whose output voltage depends not only on the position of the potentiometer arm but also on the voltage of the battery feeding these pickups? The value for the change in this voltage during flight is unknown. Moreover, the transmitted voltage can be distorted because of the non-linearity of the conversion track - the commutator and the coding device. There is only one answer to this question: we must transmit by telemetry channels, together with pickup signals, the signals of a reference source of voltage (which is very stable and accurately known in value). Thus they are transmitted. On the tapes of automatic recorders registering the signals which come from the pickups by telemetry, together with a graph of the parameter, there is periodically a trace of the voltage of the reference source. By these traces it is easy to calculate the actual voltage coming from the pickup, and thus the /26
value of the parameter.

Since there are requirements for a high accuracy set forth for modern telemetric systems (the error for the best systems does not exceed the error in a laboratory instrument of an 0.1 class), the reference sources must have a high stability.

Some good results for references are seen in chemical sources of current as, for example, zinc-mercury batteries. Their electromotive force is stable for several years, and the absolute value is determined by the electrochemical properties of the substance of the electrodes and can therefore be calculated with great accuracy beforehand.

Silicon voltage stabilizing [stabilitron] tubes have a much worse stability, but they are still acceptable in some cases. Unfortunately, the accuracy for the original voltage for the stabilitron tubes is low and varies for different samples. However, there have been serious accomplishments made recently in this range of semiconductor technology. Individual types of stabilitron tubes can approximate chemical elements in their stability.

The disadvantage in the stabilitron tubes is the need to have a relatively high voltage for supplying the sources: only in this case do the positive qualities of the stabilitron tube appear in full measure.

A further development of the idea of a telemetric system with time distribution of the channels is the system with multistage commutation. The point is that it is not at all necessary to inquire of all the pickups at a high rate. Some pickups (for example, for the temperature or the pressure in a part of the instrument) do not have to be asked several times per second: neither the temperature, not the pressure, nor the supply voltage (except, of course, for emergency cases) change substantially even for several minutes. Therefore, it is expedient that we inquire of such pickups at a much lower rate than the pickups of rapidly changing parameters. This is usually accomplished with the aid of a commutator which is analogous to the principal commutator of telemetry, only switched on by the output to the input of one of the channels of the principal commutator. This supplementary commutator is switched over from pickup to pickup only after the principal commutator searches all its pickups and begins to search again the output of the supplementary commutator. For N channels of the principal commutator and n channels of the supplementary one, the rate of searching the pickups by the supplementary commutator f_{sup} is equal to

$$f_{sup}=\frac{f_{int}}{N\cdot n}, \tag{15}$$

where f_{int} is the frequency of searching the principal commutator, i.e., the frequency of its transition from channel to channel. /27

Transmission of Televised Information

The Soviet space stations "Luna-3", "Zond-3" and "Luna-9", as well as American stations of the "Ranger" and "Surveyor" type, were equipped with television apparatus providing for transmission of those details of the Moon's landscape which could not have been obtained on Earth with the aid of telescopes. The unique photographs of the dark side of the Moon could not generally have been obtained by any other method at this stage of technical development.

Some comparative data from the television space systems are given in Table 2.

TABLE 2

Station	Date of Transmission (Beginning)	Number of Resolution Lines	Time for Transmission of One Frame	Comments
"Luna-3"	10/7/59	Up to 1000	10 min.	Photo-television System
"Zond-3"	7/19/65	1100	10 min.	"
"Ranger-7"	7/30/64	800	2.56 sec.	Television
"Luna-9"	2/3/66	6000	100 min.	"
"Surveyor-1"	6/2/66	600 and 200	-	"

The photo-television system used for the "Luna-3" and "Zond-3" stations provided for transmitting photographs of the Moon's surface many times. They were transmitted by command from the Earth. The Moon was first photographed on a motion-picture film which was then developed and fixed in a special automatic instrument. Then the film was dried and wound on a film holder, where it was preserved until the moment of transmission of the photographs to the Earth.

Transmission of the image from the film was done by the scanning-beam method.

The beam of the electron-ray tube moved slowly over the screen, scanning line by line across the film. The luminous point on the screen then "examined" the entire photograph, and, depending on the density of the negative on the photo-emissive element behind the film, more or less light entered. The photo-emissive element converted this change in light to a change in the electric signal, which went to the transmitter after amplification.

The time for transmission of one row for such a transmission /28 method could be selected to be one thousand times longer than for transmission of a usual television. This allowed for narrowing sharply the frequency band taken up by the signal, which guaranteed a high quality of reception on Earth.

Ridges, mountains, and craters similar to the ridges, mountains and craters of the visible side of the Moon were discovered on the dark side.

We should note that there has been a steady upgrading in the quality of Soviet telecommunications from space. The images of the dogs Belka and Strelka who flew in the first spacecraft were seen as if through a fog: the clearness did not exceed several tens of lines. The television transmission from the "Vostok" craft were made first with clarity of 100, and then of 400 lines. Photographs of the reverse side of the Moon were transmitted with clearness on the order of a thousand lines, and the lunar panorama was shown with unsurpassed clearness of 6000 lines. Details with dimensions of several millimeters on the lunear surface were discernible.

The television systems of the American space stations of the "Ranger" type operated while the station was falling toward the Moon, beginning at a height of about 4000 km, to 5 km. Out of nine launches, seven were unsuccessful, and only the stations "Ranger-7, 8 and 9" transmitted images of the Moon. Six television cameras were put on board the more refined station, "Ranger-9". The images were transmitted with a resolution of 1132 lines. The station transmitted 17,259 images in all of the visible side of the Moon.

Modern high-sensitivity transmitting television vidicon-tubes guarantee transmission not only by normal illumination, but also by the light of the stars. The light produced by the stars on the Earth's surface is more than one hundred times greater than their threshold sensitivity. Usage of such tubes guarantees transmission, not only from the illuminated part of the Moon, but also from the shaded part, and so much the more, because the light of the Sun reflected on the Earth illuminates this shaded part. However, for such a transmission, the station must be equipped with a heating system, which is feasible only in the case of using high-energy apparatus (for example, atomic), i.e., after transporting stations of fairly great weight to the Moon. The heavy weight of lunar stations is a problem which has still not been solved by astronautics. However, there is no doubt that it will be solved in the fairly near future.

Onboard Equipment for Processing and Analyzing Information

As we have already said, the frequency band for modern communication channels (and thus the noise-resistance) is determined by the velocity for transmitting information. A decrease in this vel- /29 ocity would allow for a very simple improvement in the reliability of the lines of radiocommunication in space.

A decrease in the transmitting velocity without a decrease in the value of the transmitted information is uniquely possible: by decreasing the excess, which is extremely great in certain types of transmitted information.

Actually, telemetric information, for example, has value as long as it gives information on the diversions of the measured parameters from the norm. (Such an approach is somewhat formal, and may meet objections, since the researcher is sometimes interested not only in emergency operational regimes, but also in the normal regime preceding it. However, we are now deriving only from the requirements for information theory.) Then we can consider finding a parameter within the field of allowable divergences as zero-information from the point of view of the ultimate results of the flight. A television signal is also interesting from the point of view of transmitting the boundaries between sections with differing intensity, and the transmission of sections of constant intensity (which is more characteristic for televising) is a transmission of data with zero-information, excluding the transmission of the first element of each section. This is why the signalers put forth these requirements: lower the excess of transmitted information and establish onboard systems for preliminary processing and analyzing of the information.

We can imagine a system (for example, telemetric) in which the information is processed onboard the station in the following way. The analyzer, which stands behind the commutator and operates synchronically with it, calculates the degree of approximation of the parameters to the maximum accepted values (determined previously on Earth and put into the block for allowable variations), after which a solution is made on transmitting one or another parameter. It is possible to construct a diagram so that not only the degree of approximation to the limit, but also the rate of this approximation, will be subject to analysis. In the necessary cases, the analyzer will then change the rate of searching, increasing it in the case of a rapid approach of a parameter to the limit.

In the American space observatory OAO, for example, it has been proposed that an onboard apparatus be used for removing the excess "scanning" up to 10,000 measurements per second (for all the channels of the telemetric system) and compressing this information to 30-400 measurements per second. In this case, the most important parameters will be transmitted rapidly, and not the values previously known which are transmitted at a rate tens or hundreds of times less. When necessary, the slow parameters can begin to be transmitted rapidly, and the transmission rate of the "rapid" /30
parameters decreases. The system of onboard processing of information was also used for the English survey satellite "Ariel", which was launched from an American booster rocket.

Systems for narrowing the spectrum of television information are also being developed. The principle for using one of these systems is included in the following.

The level of the signal for a given element of the image is stored in the memory block, after which it is compared with the level of the subsequent element. In 70-80% of these cases, this difference is equal to zero, and it is coded by a code of minimum length (an irregular code is used for transmission in this system, and the length of the "word" of the code depends on the probability of a difference in the levels). Thus we succeed in narrowing sharply the total volume of transmitted information.

It has been proposed that a system for preliminary processing of information also be established on the American spacecraft "Apollo". It will weigh more than one hundred kilograms and contain about 72,000 elements including 9600 transistors and 27,600 diodes. Telemetric and television information will be subject to processing.

Separate and Combined Systems for Space Communications

Usually, in systems of space communication, each type of information (extratrajectory, telemetric, command, and television) has its own channel. Such a division is necessary for a large number of practical reasons. One of these is the different requirements set forth for these systems. For example, the extratrajectory measurements are sometimes made with the aid of pulse-modulated signals, and it seems convenient to transmit telemetric information at the very same time by the method of partial modulation. The frequency bands which take up each type of information vary greatly, and, therefore, at a constant signal-noise ratio at the input of the Earth receiver, it seems necessary to use onboard transmitters of varying power (which is convenient from the point of view of conserving the energy of the onboard power sources). The times for operation of these systems, and the onboard apparatus with which these systems interact also vary. Moreover, the time seems convenient for producing a combined communication system, and not a separate one.

A combined system was partially used for the Soviet stations "Luna-3" and "Luna-9". Scientific and telemetric information was transmitted by one of the communication channels, and information for systems of extratrajectory measurements and television information were transmitted by another channel (this one was a combined one). /31

The American combined communication system "Telebit" has been described in literature in great detail. It was used for the space stations "Pioneer-V" and "Explorer". In this system telemetric information was transmitted simultaneously, there was communication with a terrestrial station of extratrajectory measurements, and there was also reception of the regulating commands and their transmission was controlled. The apparatus could take up to 30 commands, particularly commands for changing the regime of information transmission (the telemetric system was designed for transmission of information in three regimes: 1, 8, 64 dB. unit/sec), and for switching on the transmitter with increased power (150 W instead of 5 W, used for communication at small distances). This telemetric system transmitted information about 24 parameters, about the temperature regime of the apparatus section, and operation of the batteries, and also data from the scientific apparatus on board the station. Telemetry also controlled the transmission of commands from the regulating system. The information was transmitted "by words" and "by phrases". The "word" consisted of two synchropulses and ten information pulses, and the "phrase" consisted of one synchropulse and ten information "words" coded by the binary system. The question may arise: how could 24 parameters of information be transmitted by ten "words"? There is nothing surprising in this. The simple fact is that a multistage commutation system, of which we spoke earlier, was used in this system. The slowly changing parameters (those such as the temperature, the voltage and current of the batteries, the position of breaks in the heat-regulating system, etc.) were transmitted through a slow sub-commutator, i.e., they took up, in fact, only one "word" during transmission of a "phrase", and they were transmitted twelve times more slowly than the basic information. Out of the 24 parameters subject to transmission, only six came from the pickups in a form which was directly applicable for transmission, i.e., in binary form. The remaining pickups gave information in the form of voltage, which was converted into binary code by a special converter. Since the conversion rate was much greater than the transmission rate, a buffer storing device was established at the transmitter input. This device stored the code for the word for the period of transmission of this word while conversion and scanning of the following parameter were being made.

The "Telebit" system clearly demonstrated the basic advantage of combined systems: small weight, overall size, and use of electric power. Suffice it to say that the communication apparatus weighed 5.5 kg and used an average power of 2.4 W.

Compensation for Frequency Shifts /32

In order to guarantee communication with a station, it is necessary to have compensation for Doppler frequency shifts. The radial velocity of a space station relative to the Earth V_0 leads to a shift in the signal frequency Δf_0 relative to the nominal frequency of the transmitter f_0

$$\Delta f_0 = f_0 \cdot \frac{V_0}{C}. \qquad (16)$$

If the penetration band of an onboard receiver is narrower than $2\Delta f_0$, then a search for frequency must be conducted in the receiver, or, having forecast the velocity of the station relative to the Earth, the frequency of the terrestrial transmitter must be previously shifted. In order to receive signals from a station, the structure of the terrestrial receiver is shifted correspondingly.

The American space station "Telebit" established in the space rocket "Pioneer-V" operated at a frequency of f_0 = 378 MHz with a penetration band of the onboard receiver of Δf_{01} = 250 Hz and Δf_{02} = 40 Hz (transition from one band to the other was made by command from Earth). If we take the radial velocity of the rocket relative to the Earth as 2-4 km/sec, then the Doppler frequency shift reaches 720-1440 Hz. Thus, even for the widest penetration band, the station could not have received the signal from Earth. This caused a frequency-searching device to be introduced into the onboard receiver, which, naturally, sharply complicated the diagram. The method for forecasting the frequency shift was used in the more refined system "Azuza-Mark II".

GROUND-BASED APPARATUS FOR RADIO LINKS IN SPACE

As we have already said, the limited power of the onboard transmitters and the limited dimensions of the onboard antennas cause us to give great importance to guaranteeing operation of the radio-frequency spectral lines in space on the terrestrial apparatus. For an example, the energy relationships of the "2-10-8" system during operation at its maximum possible distance, $3.6 \cdot 10^8$ km, are shown in Figure 6. It is interesting to note that amplification of the onboard transmitter is almost fifteen times less than amplification of the terrestrial antenna.

/33

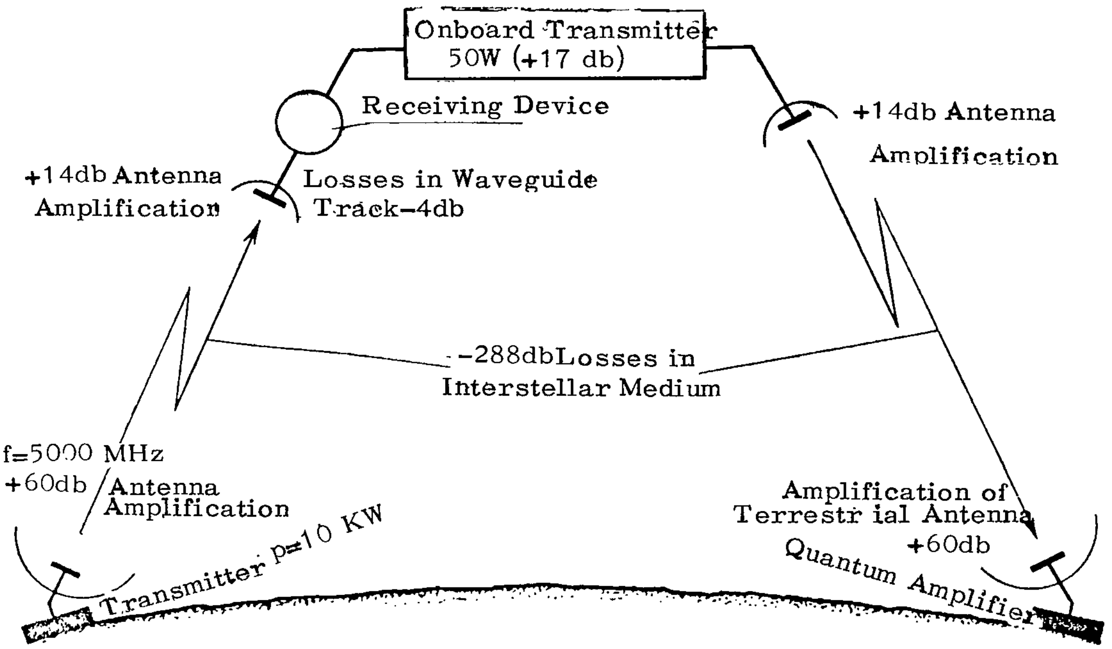


Fig. 6. Energetics of the "2-10-8" Communications System During Communications at the Maximum Possible Distance of $3.6 \cdot 10^8$ km.

Antennas and Receivers

/34

The principal requirement for the antennas is that there be a high amplification coefficient and the minimum possible bulk and weight.

These requirements contradict each other, since the coefficient of antenna amplification is directly proportional to its area,

$$G = \frac{2\pi \cdot q \cdot S_a}{\lambda} \cdot h, \tag{17}$$

where λ is the wavelength (m), S_a is the area of antenna exposure (m^2), q is the coefficient of usage of the antenna surface (usually 0.5-0.6), h is the coefficient of useful action of the antenna (usually ≈ 1).

Since the width of the directivity diagram for half the power is equal to

$$\varphi_{0,5} = \frac{70\lambda}{D}, \tag{18}$$

the attempt to obtain an antenna with great amplification results in a very narrow directivity diagram. This in turn sets forth rigid requirements for the system of antenna orientation, and also for forecasting the movements of the space station. On the other hand, the narrowing of the directivity diagram with an increase in dimensions imposes limits on the bulk of the onboard antennas, since the necessary accuracy for their orientation on Earth can prove to be extremely high and will not be provided for by the modern level of technology.

The terrestrial antennas for the lines of space communication, particularly for communication at great distances, take their shape in extreme bulkiness, complex and expensive installations. For example, the 76-meter radiotelescope of the English station, Jodrell Bank, has an antenna with a weight of 2000 tons, of which the rotating part is 800 tons. The antenna was mounted on two 54-meter towers.

However, for the radio-frequency lines, calculated for operation at relatively small distances such as Earth-to-Moon, the dimensions of antennas, particularly in the presence of a powerful transmitter at a space station, can be significantly decreased.

Calculations show that, for radio-frequency lines of Earth-to-Moon operating at a wavelength of λ_0 = 15 cm (f_0 = 2000 MHz) on the condition that an antenna with diameter of D_1 = 4.4 m and transmitter with capacity of P = 100 W be established on the Moon, the terrestrial station must be equipped with the following:

- for reception of an f-m television, an antenna with D_2 = 30 m and a parametric amplifier working at room temperature; /35

- for an a-m telephone channel, an antenna with diameter of D_2 = 2.2 m and a parametric amplifier;

- for phase-pulse modulation telegraphy, an antenna of the "wave-channel" type and a simple amplifier on a tunnel diode, a travelling-wave tube, or simply a crystal mixer.

The difference in dimensions of the antennas and types of input devices is caused by different signal-noise ratios which must be obtained at the input of the receiver for various types of information.

The struggle against noise in the terrestrial receiving devices originates from the antennas. One effective measure is to shorten the length of the feeder from the antenna irradiator to the receiver input, which decreases the "overlapping" of noises in the feeder to the signal and improves the signal-noise ratio.

In certain radiotelescopes, the vibrator on which the energy collected by the antenna is concentrated is located on special instruments at the focus of a paraboloid, so that the feeder length from the irradiator to the preamplifier (of the antenna) is very great. Today, the Cassegrainian antenna system is being used more and more often. It is so called because of the name of the inventor who proposed its use for optical systems. Its main distinctive feature is a small additional mirror located at the focus of the main paraboloid. The paraboloid directs the energy to this mirror, and the signal reflected from it goes to the vibrator. Screening of the paraboloid by the additional mirror is decreased by selecting a mirror geometry, and is completely removed by turning the plane of signal polarization in the antenna from the vibrator to the paraboloid.

These measures provide for decreasing sharply the natural noises of the antenna.

The noises of the first cascades of the receiver are a factor which substantially limit the communication distance.

It is well known that the current by travelling along the resistor R produces at its terminals a fluctuating voltage of

$$U=2\sqrt{K\cdot T\cdot R\cdot\Delta f}, \qquad (19)$$

where K is the Boltzmann constant equal to $1.38\cdot10^{-23}$ W/Hz degree; T is the absolute temperature, °K; Δf is the frequency band of the receiver.

Because of this, any noise source can lead to a certain resistance at one or another temperature. The typical noise temperatures of the first cascades of the receivers are such: molecular ampli- /36
fier - 50° K; parametric amplifier at room temperature (293° K) - 100° K; tunnel diode in liquid nitrogen (77° K) - 300° K; tunnel diode at room temperature - 600° K; TWT, diode mixer - 1500° K.

As we can see, the least noisy of these devices are the molecular and parametric amplifiers.

In terrestrial receivers of radio-frequency lines for "Earth-Moon-Earth" operating at a frequency of about 200 MHz, application of the first cascades of molecular amplifiers is not at all necessary, since a satisfactory signal-noise ratio is also guaranteed without them. It is true that the molecular amplifiers improve the reliability of positive reception, but this is linked with the necessity for having cooling devices for liquid helium, i.e., very expensive and complex devices.

The parametric amplifiers are more simple, and they operate even at room temperature. The essence of parametric amplifiers as their forces change in the parameters of the oscillating circuit (its capacitance or inductance) with a frequency that is twice that of the tuning frequency. If there are oscillations in the circuit because of the signal received, then the change in the parameter of the oscillating circuit brings additional energy to the circuit, as a result of which these oscillations are amplified.

Parametric amplification often occurs, changing the capacitance of the oscillating circuit. Let us assume that weak oscillations in the circuit have already occurred. When the voltage in the capacitor becomes maximum, let us decrease its capacitance. This undertaking increases the voltage in it in correspondence with the following formula:

$$U=\frac{Q}{C}, \tag{20}$$

After a quarter of the period when the voltage in the capacitor becomes equal to zero, let us increase the capacitance, preparing the amplifier for a new amplification cycle.

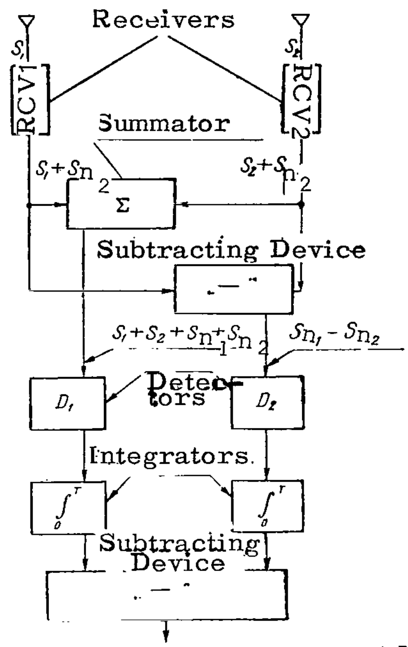
A semiconductor diode, cut off by the mixing voltage is sometimes used for the capacitor. The capacitance developing between the *p* and *n* layers because of a non-conducting layer exhausted by discharges, depends on this mixing. Moreover, there are ceramic capacitors with a capacitance that varies from the applied voltage - so-called varactors.

Under the action of a high-frequency voltage - a pumping voltage - the capacitance of the capacitor changes, and we can easily note that this voltage must be generated with a fully determined /37
phase of a relative signal received.

The parametric amplifier is bipolar, and, therefore, in contrast to the usual quadrupole amplifiers, the input and output are not clearly discernible. The signal will be amplified on the condition that it will go to the amplifier from any side. Because of this, the amplifier, if we attempt simply to switch it to a line or a wave guide, will amplify equally both the input signal, altering it to the receiver input, and the noises of the first cascade of the receiver, altering them to the antenna vibrator, from which they will again return to the amplifier. In this case we not only do not improve the signal-noise ratio but we may even make it worse.

In order to avoid this, the amplifier is connected through a special circulator which provides for a single-directionality for the amplifying properties of the parametric amplifier.

The frequency range for parametric amplifiers at diodes is very wide and reaches 30-60 thousand MHz (λ = 1.0-0.5 cm).



$2S+[(S_{n_1}+S_{n_2})-(S_{n_1}-S_{n_2})]$

Fig. 7. Block Diagram of a Memory System.

Of the other junctions of the receivers, the storage devices which provide for greatly increasing the signal-noise ratio in the receiver are interesting. By this method the signal is received at two antennas spaced apart, and is amplified by two receivers (Fig. 7). However, before transmitting signals S_1 and S_2 to the detectors, two devices are put in the way: a summator and a subtracting device. At the output of the summator, a doubled signal is obtained together with a doubled noise: $S_1 + S_2 + S_{n_1} + S_{n_2}$, and at the output of the subtracting device, we obtain the difference of statistically independent noises of both channels, $S_{n_1} - S_{n_2}$. Subsequently, after detection, the result of addition and the result of subtraction go to two storage units and then to the subtracting device. Since the noises in the channels are statistically independent, the difference between them is not equal to zero, and the sum is not equal to a doubled value of the noise in each of /38 the channels. As a result of this, the difference $(S_{n_1} + S_{n_2}) - (S_{n_1} - S_{n_2})$ is less than S_{n_1} or S_{n_2}, and the signal is doubled, which also increases the signal-noise ratio.

The signals from the space station "Mariner", transmitting televised photographs of Mars, were received by using the storage method, but in a somewhat varied form. The method, proposed by Obry, a professor at Paris University, involves photo-storage of a signal on a drum which rotates at a rate of 30-120 rpm. The illumination intensity of the luminophore which covers the drum decreases as the drum rotates but then is again amplified because of a secondary signal. In this case the signal is neutralized for several periods, and the signal-noise ratio increases because of the statistically independent noises. The device provided for increasing the signal-noise ratio by more than 30 dB, which is an outstanding achievement. The quality of the image obtained by this method proved to be very high.

Recording Apparatus

The signal received by the terrestrial apparatus is ready for further processing and analyzing. This signal is stored by different types of recorders.

The rate for processing and analyzing the signal can vary. However, in any case the recorder guarantees the possibility of repeated reproduction of the signal received at various time-rates, which is necessary, for example, for an express (surveying) and a more careful, detailed, analysis.

Despite the fact that processing of the information in computers gives the highest-quality results, it is often necessary that the experimenter subject the recordings to visual analysis. Therefore, the recorders have as a rule, besides an output to computers, an output to means for visual control.

The recorders with an output to a computer carry out their functions in the form of magnetic recorders of various types and in the form of storage devices on electron-ray tubes. The visual recorders are special movie-film apparatus or devices for recording on paper.

Historically, the first recorders which were used in communication devices were the automatic recorders which transferred data onto a moving paper tape by an ink block (or blocks). Multichannel automatic recorders are now being widely used, in particular, in physiology and medicine, for recording slow processes. The disadvantage which limits their usage is the low frequency range: not /39
more than one unit cycle per second.

Recorders with a much greater frequency range, reaching tens of thousands of cycles per second, are needed for space technology. Recording processes with such a frequency can be provided for only by automatic recorders which do not have any other moving mechanical units other than the mechanisms which provide for moving the tape. At the present time, depending on the type of carrier on which the recording takes place, the recorders are seen to be photographic, xerographic, thermoplastic, electrothermal and electrochemical.

The photographic recorders are either loop oscillographs or devices for photographing the image from the screen of an electron-ray tube.

The movement of the tape along the screen produces a time axis, and the beam deflection is the value of the parameter. In principle, it is possible to record from the screen of one tube several parameters simultaneously, for which the deflection signals synchronize with the pulses triggered by the electron beam and go to the plates through a rapidly moving electronic switch.

The disadvantage of this recording method is the expensiveness of the tape and the chemicals for its processing, and also the danger of losing information during accidental exposure of the tape or an abnormal photo-processing regime.

The xerographic recorder is a variation of the photo-recorder, differing from it by a lack of photo-tape or photo-paper. The recording is made on ordinary paper. The cylinder, covered by a film of selenium, is charged negatively by the effect of the light of a beam from the electron-ray tube. Coming in contact with ordinary paper, it transfers a charge to the paper, and it is charged itself then by the light of the ultraviolet tube. The paper is then dusted with a special powder which is retained only on those places to which a charge is transferred, and the powder is ultimately set by heating the paper. Therefore, the powder must be subject to fairly rigid requirements: first of all, the charge must have the opposite sign in relation to the charge of the drum; secondly, its particle must be very small (acceptable sizes are 5-75μ); and thirdly, its melting temperature must be lower than the temperature at which the paper yellows (i.e., +165°C).

The thermoplastic recording method is carried out on a special tape consisting of three layers: the lower is plastic with a high melting temperature, the middle layer is conducting material, and /40 the upper layer is a thin (about 12 μ) layer of plastic material with a low melting point. For the material of the upper layer, it is necessary to have celluloid, polystyrene, polyethylene, and other substances with a melting point of 40-100°C.

The signal is recorded on the tape by an electron beam from a special projector so that those places through which the beam has passed are negatively charged. The recorded tape passes by a high-frequency heater which melts the upper, easily melted layer. Because of the pull between the negatively charged upper layer and the positively charged conducting layer, the thickness of the upper layer decreases, i.e., a unique groove is formed on the tape. After going out from under the heater, the tape solidifies and the information is stabilized. The entire recording and "developing" process takes no more than one hundredth of a second. After it is no longer necessary to preserve the recorded information, the tape can be "erased" by heating it to a higher temperature than during the "development". In this case the charges discharge because of the higher conductivity of the tape in a heated state, and the surface of the upper layer becomes equal to what it was before the recording.

With the aid of such a device it is possible to record television images also.

Thermoplastic recording is characterized by a great density of information recording, which exceeds the density of the recording on a magnetic tape.

Electric and electrochemical methods of recording differ only by the type of paper on which the recording is made. For electrothermal recording a paper is used which is saturated to the limit with carbon and covered on one side with a thin film of aluminum (which guarantees electrical contact for the paper and makes it uncontaminated), and on the other side with a mixture of lead thiosulphate and titanium oxide. When an electrical spark hits the paper, the thiosulphate and titanium oxide melt, and a dark spot appears on the surface of the paper. When the paper is pulled through, the spots melt into a line which characterizes the change in parameter.

During an electrochemical recording, the paper tape is saturated directly before the recording with special compounds which decompose and dye the paper a dark color when affected by the current.

Both of these recording methods require producing devices which guarantee supplying current on the paper tape, as well as a fairlv rapid transfer of the point for supplying the current in correspondence with the change in parameter.

For this purpose, so-called "distributing blocks" are used. /41
They are fastened securely to a series of hundreds of thin (diameter of 0.2-0.3 mm) tungsten or platinum-iridium electrodes. Supply of current at one or another electrode in correspondence with a change in parameter also results in the appearance of graph lines on the tape.

The number of electrodes in a distributing block is determined by the number of code discharges, with the aid of which the information is transferred by radio-frequency lines: for an n-discharge code, the number of electrode-points must be no less then 2^n. Special rapidly moving electronic devices select the electrode at which the voltage must be given at a given moment. The code signals received by the receiver go to the intermediate-memory block, where they are converted from a translational to a parallel form (the code discharges were transmitted in series, discharge by discharge, by the radio lines, and each discharge was stored in the intermediate memory block in its unit with two outputs - "zero" and "one").

The number is fed from the memory block to the matrix which determines the "address", or the electrode in the distributing block at which the voltage must be supplied, for a given number recorded in the code.

The power at the outlet of the matrix is small. Therefore, before feeding into the distributing block, it is amplified by special amplifiers, the number of which is equal to the number of teeth of the distributing block.

The inertia of the recording systems using distributing blocks with electronic control is very low. The frequency for a change in the recorded parameter can reach 10 kHz and more, and the velocity of transporting the paper tape is greater than 1 m/sec.

During recording on a paper, the time characteristics are usually recorded, which as a consequence also provides for comparing the behavior of various parameters and estimating the course of development of one or another process. A special duty of a unit time (DUT) yields the time characteristics. Because of its operation, all the received points are connected with one another, and the information received is recorded on magnetic tape and devices for open recording in a form suitable for comparison.

Moreover, the calibration levels are usually recorded on the paper together with the lines of a parameter. This provides for calculating the visual value of the parameter with a fairly high accuracy. Using calibration curves and tables, the experimenter can determine the real value of a parameter also: of the temperature, the pressure, etc.

The visual recording can be developed with much greater accuracy on special optical apparatus - modified epidiascopes and diaprojectors (the first for opaque paper, and the second for movie-film tapes). The tape is seen within the field of vision of such /42
an apparatus, as well as the scale, which provides for calculating the value of a parameter within fractions of a percent. A coordinate system is often put within the field of vision. This is done by calculating the characteristics of a pickup. Then the real value for the measured parameter is immediately calculated by the curve.

Devices for preliminary recording, generating the recording of the feeding information at the rate of reception, are usually magnetic recorders. As a rule, they are very expensive magnetophones with exceptionally high-quality indicators. The penetration band for such magnetophones by a recording-reproduction circuit is very wide and comparable with the penetration band of magnetophones for recording a televised signal. This allows for recording information practically without any distortions.

The recording is usually made in a binary code, and each discharge is recorded on its own track. DUT signals are recorded on a special track.

The requirements for broaching stability in such magnetophones are much higher than in the best studio devices for music recording: it cannot be less than 0.1%. Such a high stability is achieved by special methods. For example, in a "Daytone" S-752 magnetophone, a signal of 17 kHz, modulated at a frequency of 60 Hz, is recorded on tape. A frequency-modulated signal from the magnetophone output is comparable with a signal from a master generator at a frequency of 60 Hz. If the broaching velocity is unstable, the signal at the output will differ from the frequency from a signal of the generator. The difference signals arising in this case by an automatic control system change the rotation rate for the leading engine, stabilizing the broaching velocity.

The electronics of terrestrial magnetic recorders is analogous to the electronics of recorders for onboard storage devices, of which we spoke earlier, but differs in its higher-quality characteristics.

TECHNICAL DATA ON SOME RADIO-FREQUENCY LINES

For an example of communication, let us examine the radio-frequency line of the spacecraft "Apollo" which, according to the plan of American researchers, is expected to land astronauts on the Moon.

Two-way communication with the spacecraft will be maintained within a range of 5000-1500 MHz, i.e., in the range which is most advantageous for distant space communication.

The onboard apparatus will provide for: two-way telephone com- /43
munication with the Earth, reception of commands and telemetric information from the Earth, transmission to Earth of telemetric and television information, and operation in a response regime for stations of the terrestrial complex for extratrajectory measurements.

All these functions will be carried out by a unified receiver-transmitter which consists of a receiver operating in two regimes (reception of commands from Earth and reception of signals from the extratrajectory complex) and a transmitter operating also in two regimes (low capacity of 300 W and high capacity of 5 or 20 W, depending on the type of traveling-wave tube installed).

From the Soviet radio lines for "Earth-Moon-Earth", let us examine the radio line which is used during transmission of an image from the space station "Luna-3".

The image is transmitted at a frequency of 183.6 MHz in a continuous regime by a frequency modulation method. All the onboard devices, as well as the terrestrial apparatus, were duplicated for the sake of high reliability. Particular attention was paid to the weight and bulk of the instruments. This provided for making more space for sources of electric energy and for adding to the capacity of the transmitter by several watts. Despite this fact, the power of the signals received did not exceed one hundred-millionth of that average power which goes to the antenna of a regular television receiver. Nevertheless, the television transmission from space was received. Its quality proved to be very high.

BRIEF NOTES OF INTEREST /44

At the time that this book was being assembled, the radio announced that Soviet researchers of the Moon have made new achievements. Station "Luna-12" was put into the orbit of a lunar satellite. It photographed the Moon from a height of about 100 km. The photographed region (the areas surrounding the Aristarchus Crater) is of special interest to scientists. The fact is that a strange spot was found around this crater. This spot had exceptionally strong absorption in ultraviolet rays. Other strange phenomena were also observed. The flight of this station was similar to the flight of "Luna-10" and "Luna-11" stations. After photographing, the station turned to a regime of television transmission and transferred the photographed images to the Earth.

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Station "Luna-13" took off in the path of "Luna-12" into space, made a landing, and transmitted, as did "Luna-9", a televised panorama. Moreover, the first instruments in the world for measuring properties of the Moon's soil (its density and firmness) were transported to the Moon's surface. The data from these instruments provide exceptionally interesting materials for science.

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Station "Luna-10" measured many physical constants of the space surrounding the Moon. Radio-frequency lines gave scientists invaluable information about our satellite. The problem of the lunar atmosphere was ultimately solved: if it exists, then its density does not exceed 10^{-13} of the density of the Earth's atmosphere, which practically means that it completely does not exist. In view of this, the ionosphere peculiar to the Earth does not exist around the Moon. Communication on short waves, in contrast to terrestrial conditions, can be adjusted on the Moon only within the limits of direct visibility. The radiowaves do not reflect from anything, and, like ultrashort waves, they will go out into space. It is possible that a shorter way for radio-communication between separate points on the Moon will be communication through the Earth.

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Maps of the Moon have been made since the sixteenth century. But more than 35,000 objects, located on the visible side of the lunar disk, have been accumulated in modern catalogues. There are even more details on maps of the Moon: we can find there up to 200,000 objects with dimensions from 300 meters and more. Maps of the Moon are being made on a very large scale at this time - ten kilometers per centimeter. Tourists can go by maps of such a scale on the Earth.

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Lunar stations rotating in orbit around the Moon have provided /45
for making the outline of the Moon very accurate. Thus, according to data from the American station "Lunar Orbiter", the Moon has a slightly pyriform shape: it protrudes approximately by a quarter of a mile (about 400 km) at the Northern lunar pole, and is compressed by just as much at the Southern pole. The diameter of the Moon in the plane of the equator is somewhat less than if it were

an ideal sphere, and the southern hemisphere is "more complete". The force of gravity at the Moon's surface, in complete correspondence with theory, is equal to one-sixth the Earth's gravitation.

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A transmitting laser camera shows great promise for televising in space. A laser ray in this low-power camera turns around by lines and frames with the aid of a system of two rotating many-sided mirrors: one which rotates at a velocity corresponding to the frequency of the lines, and the other rotating at the velocity of the frequency of the frames. Thus, the ray "examines" the transmitted scene line by line. The reflected light is detected by a photoelectron multiplier, converts to an alternating current, is amplified, and goes to the transmitter. The very important advantage of this system is that it does not need focusing: all the objects in a radius determined by the capacity of the reflected ray (the capacity must be higher than the capacity of the noises) prove to be sharply represented. The system can operate in complete darkness.

Laser transmitting systems have also found usage in the technology of space communication. One such system, having undergone experiments under terrestrial conditions (developing firm - "Hughes Aircraft"), was calculated for transmission coded for three types of information: a television channel with legibility of 400 lines, a channel for telephone communication with a band of 4 kHz, and a telemetry channel with a band of 1 kHz. What was most interesting in this system was the method for code manipulation: "1" was transmitted to the right-hand circle of beam polarization, and "0" went to the left-hand polarization circle.

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There are no theoretical difficulties for transmitting data at a high rate (up to 1000 signs per second). However, a noise lasting only 0.1 seconds distorts one hundred signals. In order to avoid this, it is possible to transmit along two communication channels, the information being transmitted in one of the channels with a small time delay. Information is received, naturally, by calculating the delay. An experimental transmission by this method showed excellent results: 9 errors in all for 3 million signals. A similar two-channel system, but without delay, gave 1664 errors.

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More and more large-scale radiotelescopes are being constructed for distant space communications. At a symposium of the Institute of Radio Engineers (USA) in 1966, a project was established to construct a gigantic telescope consisting of 10,000 antennas with a diameter of about 30 m, and phased in a corresponding manner. The resolving power of this fantastic structure, according to the planners' calculations, must reach the resolving power of an optical telescope with a mirror of 9.5 cm in diameter. The approximate cost of the structure is 5 billion dollars.

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Transition to microminiaturization provides for decreasing sharply the bulk, weight, and the required energy for an onboard apparatus. Thus, the coding device for one of the foreign tele- /46 metric systems, after converting to microfilm, decreased 13 times over in volume, and the necessary power decreased by a factor of 5.

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The reliability of radio-parts is continuously increasing. It is particularly high for those parts which help to outfit radio-apparatus for rockets and space objects. Thus, for example, the intensity of failures, obtained for preserving the "Minuteman" rockets, is such (per 1000 hours): condensers - $27 \cdot 10^{-8}$, semiconductor diodes - $32 \cdot 10^{-7}$, resistors - $33 \cdot 10^{-8}$, transistors - $23 \cdot 10^{-6}$ and transformers - $14 \cdot 10^{-6}$.

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High reliability is obtained by careful experimentation for all radio-parts except those which go into space electronic instruments. These experiments are indeed beastly. Judge for yourself the series of experiments for semiconductor triodes (as well as for other parts) intended for operation in the apparatus of the spacecraft "Apollo":

Careful exterior examination;

Mechanical test for the centrifuge with acceleration of 20,000 g;

X-raying to sift out triodes with broken or partly broken outputs inside an air-tight framework;

Testing for the electrical parameters at temperatures of -55° C and +125° C;

Exposure at a temperature of +125° C for 168 hours;

Second testing for the electrical parameters at temperatures of -55° C and +125° C;

Five thermal shocks at -55° C and +125° C with momentary exposure at room temperature;

Test for air-tightness;

Third testing of parameters at -55° C and +125° C.

One hundred percent of the parts undergo testing.

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